ULTRASOUND SKILLS LABORATORY

Medical Imaging Methods
Compulsory Subject for 3rd Year Students

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Budapest

2017

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Contents

The present material was assembled to support the execution of the Ultrasound (US) Skills Laboratory by providing a concise guideline. The lab should be carried out according to the logical sequence of the information provided in the following paragraphs.

1. First Steps

Introduction: explanation of the instructor setup: instructors come from the anatomy and biophysics departments. There is one instructor and 4–5 students for each US device.

Reminder of the mission of the subject: acquiring the physical principles of diagnostic imaging methods and the relevant anatomical knowledge.

Reminder of the aim of the present lab: demonstarting and practicing the **basic manual skills** related to US examination. Students learn and practice the examination on each other. Students will examine the abdominal and cervical regions. It is NOT the purpose of the lab to demonstrate pathological lesions – that will be taught within the subject of radiology.

2. Short Summary of US Principles

Ultrasound: a mechanical wave with a frequency exceeding the range of sensitivity of the human ear (16 Hz – 20 000 Hz). Ultrasound frequencies used in diagnostic practice fall in the range of 1–30 MHz. The actual frequency is usually indicated on the transducer in use.

Transducer: a device consisting of several piezoelectric crystals and used for producing and detecting US. US is produced by the **inverse piezoelectric effect** (deformation of the piezoelectric crystal in electric field), and detected by the **direct piezoelectric effect** (electric polarization of the crystal due to mechanical deformation). The shape of the transducer (i.e. the geometry and arrangement of the piezoelectric crystals) may be **linear** or **curved convex** (fan shaped). The transducers used for echocardiography (also known as sector transducers) are small in size and work at a high frequency.

Principle of US imaging: pulse-echo principle. The US pulse emitted into the body is reflected from the various surfaces. The distance between the transducer and the reflecting surface can be calculated from the time elapsed until the detection of the echo and the speed of the ultrasound. The image is constructed from the calculated reflection distance (depth) and the intensity of the reflected sound. On the boundry between media with very different acoustic impedances **total internal reflection** may occur. Examples for media transmitting US poorly are air, gases, and bone. The medium transmitting US the best is free liquid. The air trapped between the transducer and the body would hinder imaging, so this gap is filled with a well transmitting coupling medium, the US gel. Different organs contain different amount of reflecting surfaces; this determines the quality of the images produced from them, that is, their **echogenicity**. With respect to echogenicity we can distinguish the following objects: **anechoic** (or anechogenic, echo-free: no reflection, i.e. it produces a black area in the images but there is acoustic enhancement behind it like in case of a cyst), **hypoechoic** (or hypoechogenic, echopenic, echo-poor: little reflection), **isoechoic** (or isoechogenic: echogenicity is similar to that of its environment), **hyperechoic** (hyperechogenic: many reflections so it is white in the US image), and **echodense** (hyperechoic with an acoustic shadow behind it due to total internal reflection, e.g., a calculus).

US modes of operation, images: The most often used imaging mode of operation is the **brightness** or **B-mode**. This is a two-dimensional gray scale image created by projecting a ray of US from the transducer into the body. Since the position and direction of the transducer is determined by the examiner, the projected image will display an **arbitrary** cross-section of the body. The **M-mode** (M for motion) image is created by recording a B-mode image along one axis as a function of time. In this case the vertical axis of the image represents the spatial (depth) information while the horizontal axis represents time, thereby enabling the representation of spatiotemporal processes (e.g. the motion of cardiac valves or the myocardial wall). If ultrasound is reflected by the surface of a moving object (e.g., corpuscular elements of the circulating blood), its frequency will change: if the surface moves towards the detector, then the frequency increases, if, however, it moves away, then the frequency decreases (**Doppler effect**). These changes can be displayed using the **Color mode**, when different hues of red and blue representing the direction and speed of motion are combined with the two-dimensional B-mode image (superposition). The default color coding is red for objects moving toward the transducer and blue for objects moving away from it (Blue Away - Red Towards = BART), but the user may change this setup. Instantaneous frequency changes caused by moving surfaces can be made audible and visible using the **Power mode** (PW).

3. Short Description of the US Device – a Concise Knobology

Fig. 1 shows the control panel of the US device used in the lab; the most important buttons and knobs are labeled with red numbers. Knowledge of the detailed "knobology" is not necessary to carry out the lab successfully, but the knowledge of the functions of the labelled knobs is very useful.

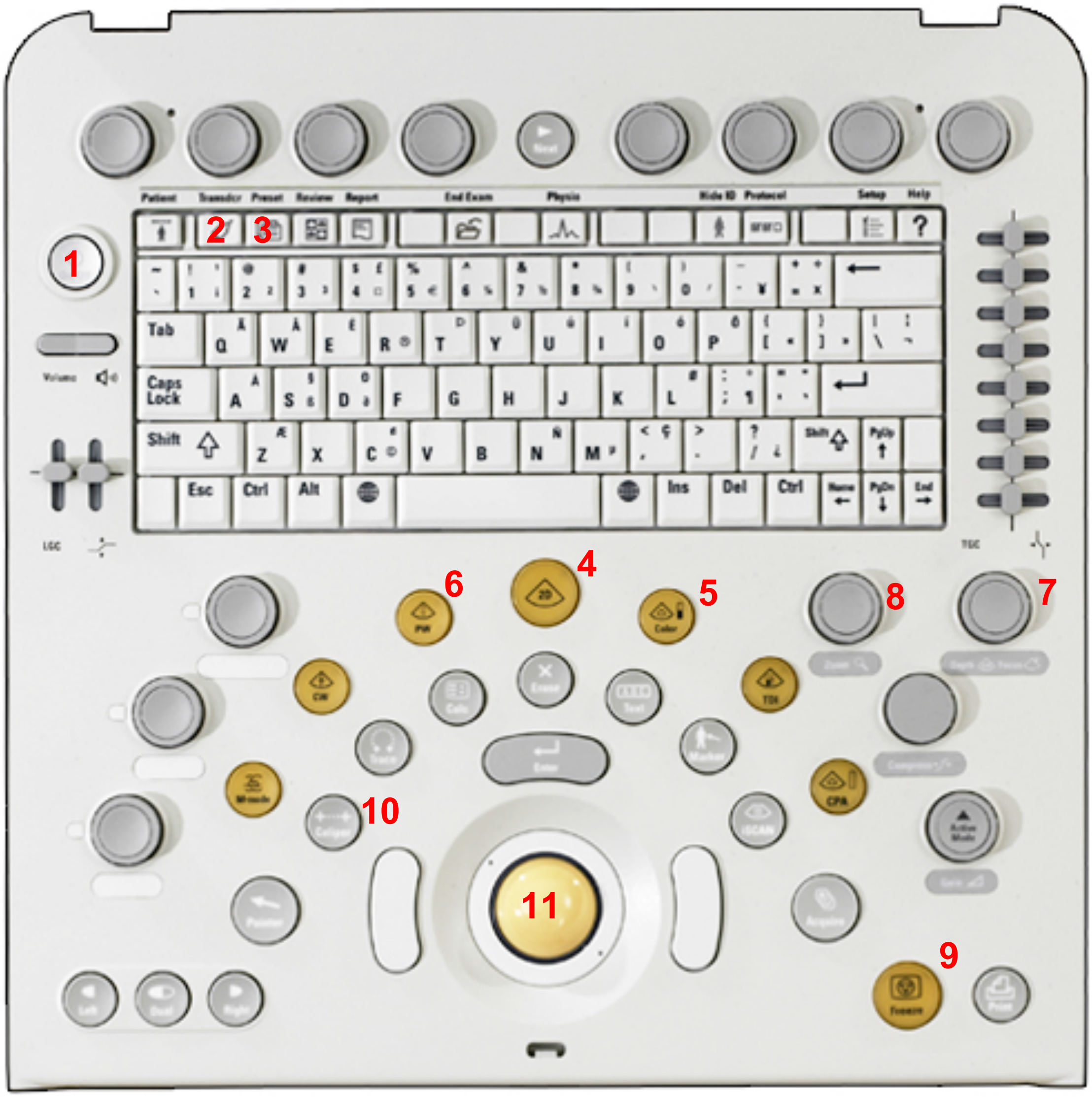

Figure 1. The control panel of the Philips CX50 US device used in the lab.

1. Power
2. Select transducer
3. Select complex, body area, and organ specific presets
4. Select 2D B-mode image
5. Select Color (Doppler) mode
6. Select Power mode
7. Set focus and amplification
8. Set zoom
9. Freeze image. Especially useful when carrying out measurements

10. Caliper for measuring distances. It requires the selection of a starting and an end point.
11. Trackball for positioning the cursor, the caliper, and setting the window size in Color and Power mode.

4. Safety Aspects of Lab Work

The relevant aspects of the patient as well as the student volunteering for examination in the lab (examined subject) and the US device are summarized below.

Protection, dignity and respect of the examined person: ultrasonography is a non-invasive imaging method, the subject is not exposed to dangerous radiation. The applied coupling gel is water-based and water-soluble, harmless, can be easily wiped or washed off the body surface, and can easily be removed (by laundering) from garments. Paper tissues are provided for removing the gel. In the lab the abdominal and cervical regions are examined on volunteering students as subjects. Abdominal examination requires the exposition of the abdomen (i.e. partial removal of clothing) so the ideal subject is a male student with a not too hairy belly. Especially demonstrative images can be acquired from skinny subjects with full urinary and gall bladder (i.e. those who drunk a few hours before the lab something other then tea or hot chocolate but did not eat anything). Show adequate respect and humility during the lab and refrain from any intimate or personal remarks. As part of protection of personal rights it must be expressed that the results of the examination have no (not even preliminary) diagnostic value at all.

Protection of the device: the US device is an expensive, cutting-edge, high-quality instrument also used in medical practice so adequate care is expected. Special care has to be taken when using the transducer (each costs several thousands of euros) and its cable. Never pass a transducer from hand to hand (as it may be accidentally dropped), it always must be put back to its place then the next examiner will take it from there. Also pay attention to the cable of the transducer in order to avoid someone stomping on it or otherwise causing a crack in it.

5. Examination

During US examination the image is produced in a plane chosen by the examiner. Therefore, the represented plane is always somewhat arbitrary, even though we try to follow certain standards.

Positioning of the subject: during the abdominal and cervical US examination carried out in the lab the subject should lie on the back. For the abdominal examination the pants should be loosened and pulled down a bit. Cover the edges of the clothing with paper tissues for protection. The subject should place the arms above the head to make the examined region more accessible. The examiner sits on the right side of the subject and uses the right hand to move and position the transducer. The abdominal examination – especially that of the kidneys and the spleen – may require that the subject lies on side. In this case the arm should again be laid above the head. To improve the examination of organs below the costal margin (liver, spleen) ask the subject to inhale deeply and hold the air so that the edge of the organs is pushed below the costal margin by the contracting diaphragm. Do not forget to instruct the subject in time to exhale or breathe normally.

Using the US gel: we use US gel to get optimal US coupling. Put the gel on the edge of the transducer, not onto the body of the subject. During the examination repeated addition of gel may be needed. US gel is needed because there is strong US reflection from the transducer–air surface that prevents the penetration of enough US intensity into the body. Lack of coupling gel is seen as an acoustic shadow in the image. Thus, if vertical shadows begin to appear on the US image, think of adding more gel.

Selecting the transducer: The convex (curved) transducer provides the deepest penetration into the body; this should be used for the examination of the abdominal region. The linear transducer is more appropriate for the examination of superficial structures so use this for the examination of the cervical region.

Positioning of the transducer: Hold the transducer in your right hand like a pencil so that the reference marker on the side of the transducer faces your thumb. In this case the orientation of the image is correct: the structures appearing, for example, on the right side of the displayed image are also found on the right side (of the examiner) in reality. The main principle is that the position and direction of the transducer set by the examiner will determine the plane of imaging. As a general approach, move the transducer cranio-caudally during the examination. That is, a recommended order of examination is: pancreas, liver and biliary ducts, spleen, kidneys, pelvis. During the examination determine the shape (margins), size (measurable with the caliper), inner structure (echogenicity, internal anatomical details such as position of blood vessels), blood supply.

Moving the transducer: besides positioning, the transducer should also be tilted (forward–backward, right–left) and rotated to achieve better visualisation of the various structures.

Recommended examinations: during the examination of the **abdominal region** locate and visualize the liver and the bile ducts, eventually the spleen as well as the kidneys. In case of the liver inspect its margins, lobes, echogenicity, characteristic inner structure (position of vessels). Find the gall bladder, determine its echogenicity, measure the thickness of its wall. Measure the size of the spleen. Examine the size and inner structure of the kidneys (cortex, medulla, renal pelvis). If possible, examine the blood supply of the organs; this is easier when using the Color mode and the Power mode. During the examination of the **cervical region** inspect the shape and echogenicity of the thyroid gland. Examine the common carotid artery as well as the jugular vein in Color mode.

6. Expected Outcome Requirements of the Lab

Working with the US device: Each student should hold the trancducer in hand and carry out a basic examination: display a US image and characterize it with his/her own words. Use the B mode, Color mode and the Power mode as well as the caliper. Observe real-time motions of the organs (e.g. carotid pulsation, displacement of the liver due to inhalation, gastric peristalsis, movements of the intestines, ureteric jet effect) while the transducer is held in one place.

Examination of the abdominal region: Students should observe and characterize the shape and structure of the liver, its blood vessels, ducts, ligaments, the gall bladder, the spleen, the kidneys, the aorta and its visceral branches (celiac artery, superior mesenteric artery) as well as the inferior vena cava.

Examination of the cervical region: Students should inspect and characterize the thyroid gland. Students should be able to differentiate the carotid artery from the jugular vein. This can be achieved by gentle compression: compression decreases the cross section of the vein.

7. Holding, Moving and Positioning the Ultrasonic Transducer

Transducers. There are three important kinds of transducers in general ultrasonographic practice that will also be shown in the lab (**Fig. 2**). Sector transducers (**Fig. 2a**), which are used in echocardiography, emit a beam of high-frequency ultrasound forming a fan by means of either a mechanically rapidly rotated crystal or a special electronic control (time shifting). Its advantage is that it enables scanning through a small window (i.e. intercostal space) and produces a high-resolution image at greater depths. Its disadvantage is that the resolution of superficial structures is low. Linear array transducers (**Fig. 2b**) use a set of piezo crystals arranged along a straight line. Its advantage is that it provides very good resolution of superficial structures while its disadvantage is that it requires relatively large scanning window. In curved transducers (**Fig. 2c**) piezo crystals are arranged along an arc. Its advantage is that it is a good compromise between sector and linear array transducers. Its disadvantage is that the resolution decreases with increasing depth due to the divergence of the ultrasound beams.

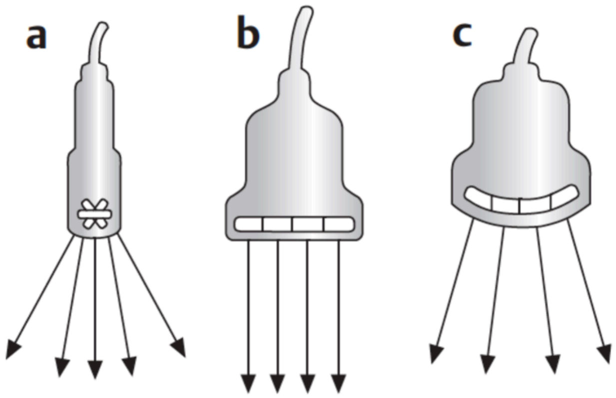

Figure 2. Types of transducers. **a**: Sector or echocardiographic transducer. **b**: Linear array transducer. **c**: Curved transducer.

The transducer is best held like a pencil. The thumb is placed on the handle of the transducer so that it is on the same side as the marker. The marker is a distinctive line along the handle of the transducer. On the screen the position of the marker is indicated with a letter "P". Paying attention to this is important in order to be able to navigate on the displayed image and to make our interpretations according to the orientation of the transducer. A general but not exclusive rule is that the thumb points in the cranial direction when the transducer is rotated.

Projection planes. An adequately held transducer produces images from specific planes. The main planes of image projection are the transverse (horizontal), the longitudinal (sagittal), and the coronal (frontal) planes (**Fig. 3**). It is important to mention, however, that during an ultrasonic examination the examiner dynamically chooses and changes the planes of projection, thus the actually scanned plane may vary greatly.

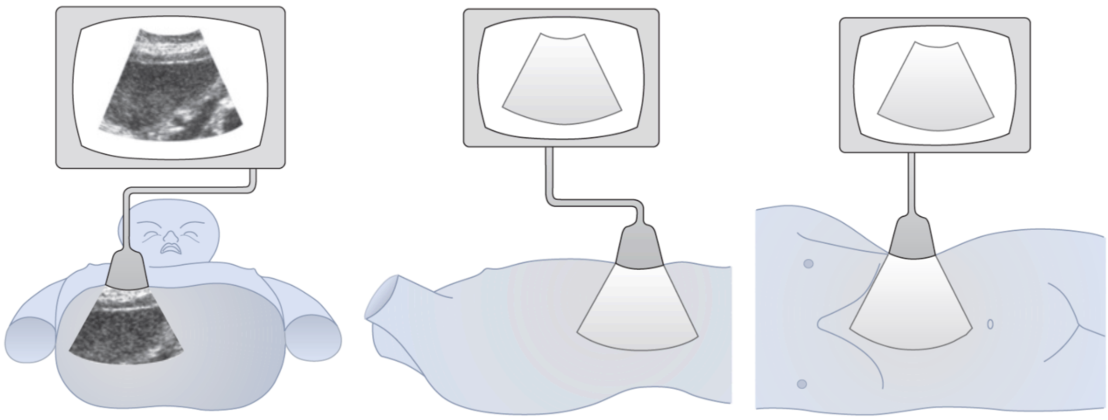

Figure 3. Principal planes of projection. **a**: Transverse or horizontal plane. **b**: Longitudinal or sagittal plane. **c**: Coronal or frontal plane.

Standard planes. In case of abdominal ultrasonography (see below) scans are best carried out in one of the standard planes (**Fig. 4**).

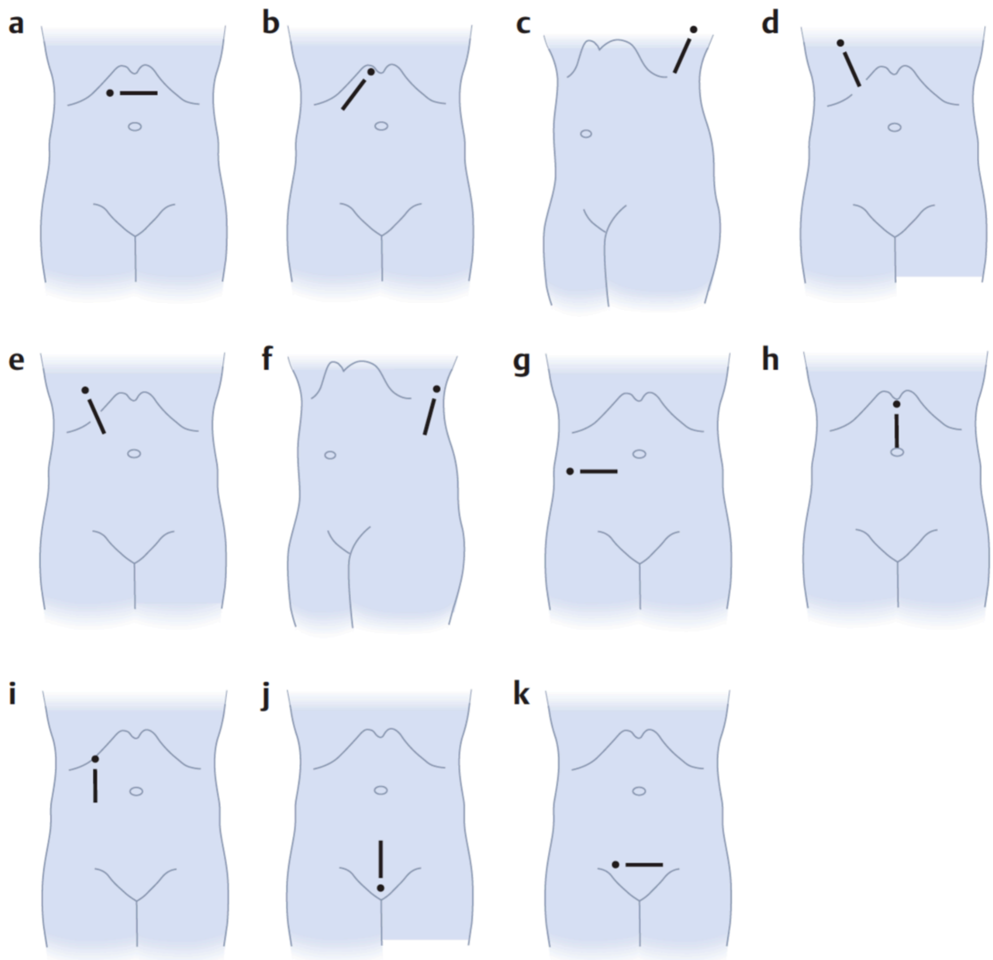

Figure 4. Standard planes for abdominal ultrasonographic scans. The thick black line indicates the position and plane of the curved transducer while the black spot at its one end the position of the thumb. **a**: Upper abdominal transverse plane. **b**: Oblique subcostal plane (in the image on the right side; a symmetric plane is used on the left side). **c**: Upper lateral intercostal plane (right or left). **d**: Intercostal plane (right or left). **e**: Extended intecostal plane (right or left). **f**: Pubic plane (right or left). **g**: Mid abdominal transverse plane (right and left).

h: Upper abdominal longitudinal plane. **i**: Parasagittal plane (right or left). **j**: Lower abdominal longitudinal plane. **k**: Lower abdominal transverse plane.

Manipulation of the transducer. The most important characteristic of ultrasonic imaging is that the examiner moves the transducer freely on the body surface of the subject in order to set the plane to be scanned. The various transducer manipulations are summarized in **Fig. 5**.

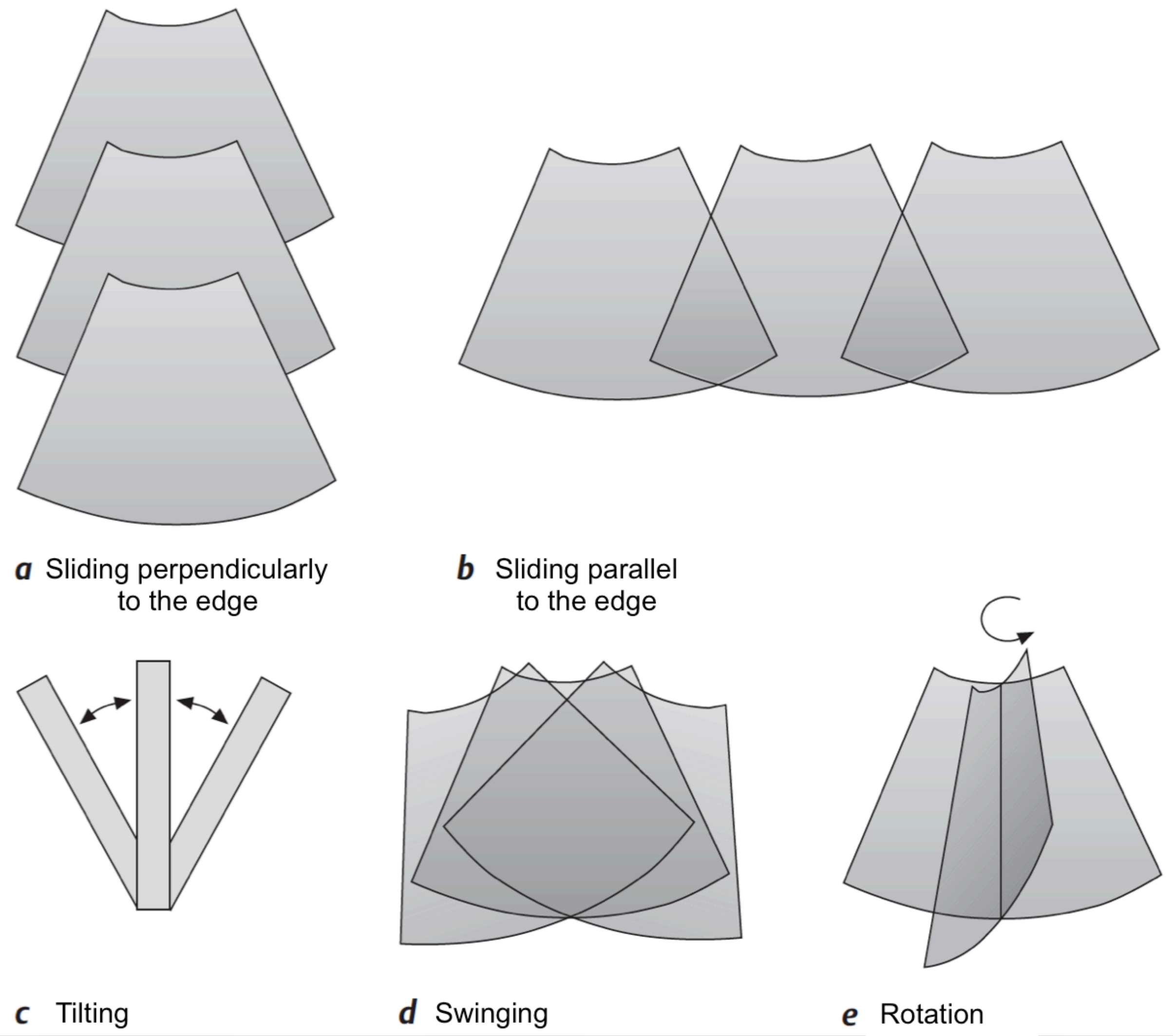

Figure 5. Manipulation of the ultrasonic transducer.

8. Artefacts

A wide range of artefacts may affect ultrasonographic images. Artefacts are such reflections which do not correspond to actual anatomical structures. The reason of their occurrence is related to the physical principles of ultrasound propagation. Here we mention only the most important ones. **Noise** (**Fig. 6**) appears in the form of granular echoes mostly on the proximal side (i.e. the side closer to the transducer) of cystic regions. It is caused by high gain in the near field. It can be reduced by reducing the gain. **Acoustic shadowing** (**Fig. 7**) behind an irradiated structure is the anechoic region along the axis of the ultrasound beam. It is caused either by total reflection (e.g. by air or intestinal gases) or by absorption (e.g. by bones, gallstone, kidney stone). **Reverberations** (**Fig. 8**) are series of parallel lines appearing perpendicularly to the ultrasound beam. They appear when the ultrasound pulse is reflected multiple times back and forth between close surfaces with significantly different acoustic impedances. **Mirror image** (**Fig. 9**) is a virtual image appearing behind a highly reflective surface (e.g. the diaphragm).

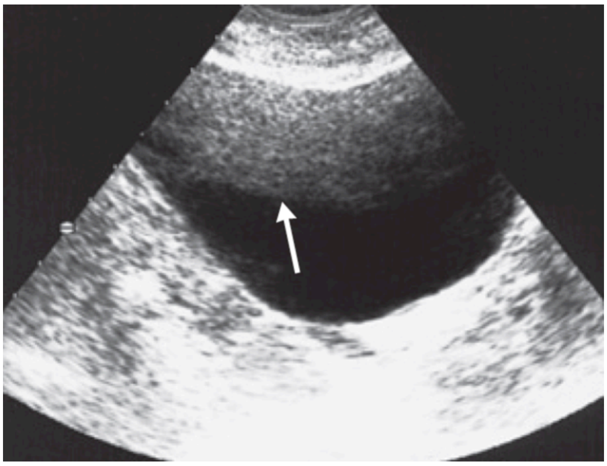

Figure 6. Noise (arrow) in the ultrasonographic image.

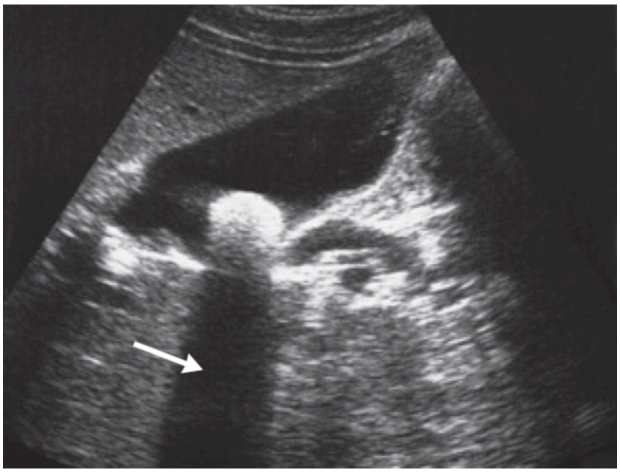

Figure 7. Acoustic shadowing (arrow) behind a gallstone.

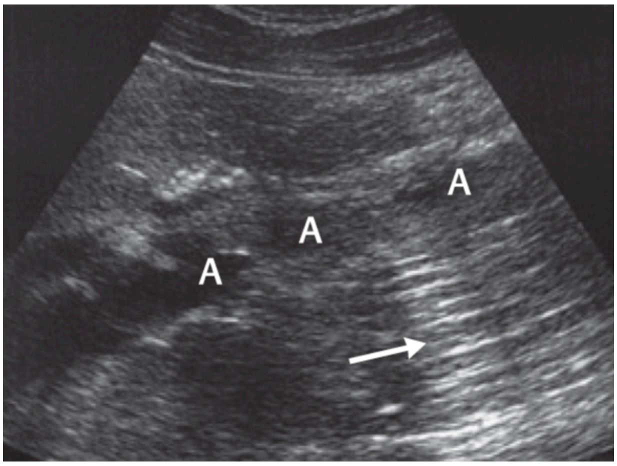

Figure 8. Reverberations. Multiple line-shaped reflections (arrow) perpendicular to the ultrasound beam. "A" indicates the position of the wall of the aorta.

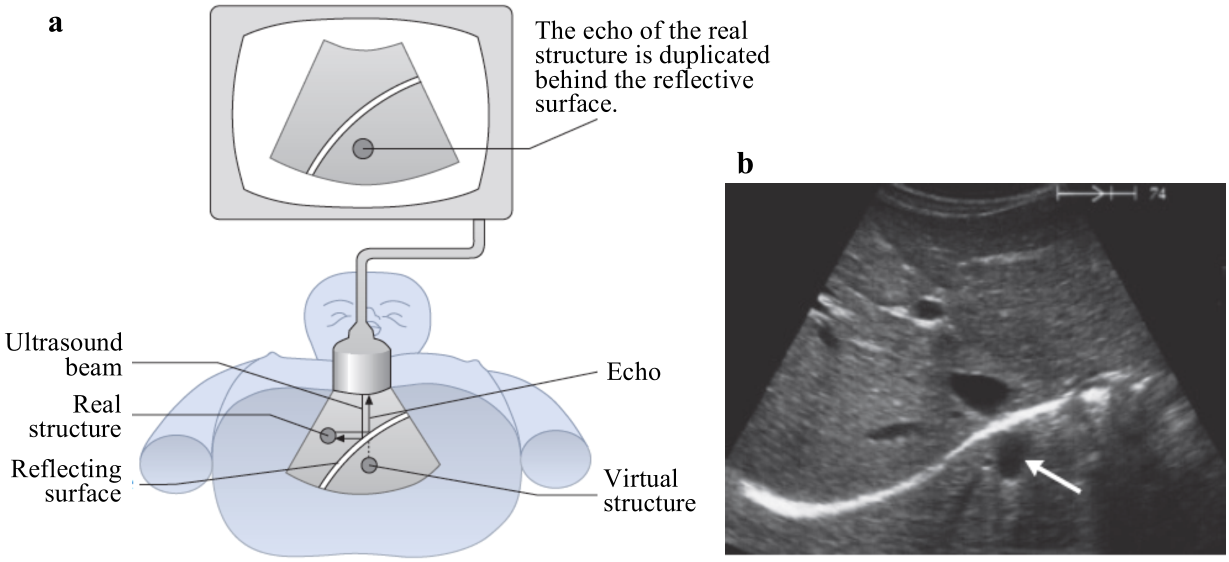

Figure 9. Mirror image artefact. **a**: Schematic of the formation of the artefact. **b**: Ultrasonographic image with mirror image artefact (arrow) appearing under the diaphragm.

9. Steps of Abdominal Ultrasonography

General principles. During abdominal ultrasonography a cranio-caudal progression is recommended. Begin with the scanning of the epigastric region (pancreas and splenic vein), then continue through the upper abdominal (liver, spleen), mid abdominal (kidneys, major blood vessels), and pelvic regions (urinary bladder, uterus, prostate). Scan throughout the whole volume of parenchymal organs both in longitudinal and transverse planes. Observe organ margins and echogenicity as well as eventual pathological structures in the parenchyma (e.g. cysts). – The most relevant scans are shown according to the order given above, together with the approximate orientation of the transducer.

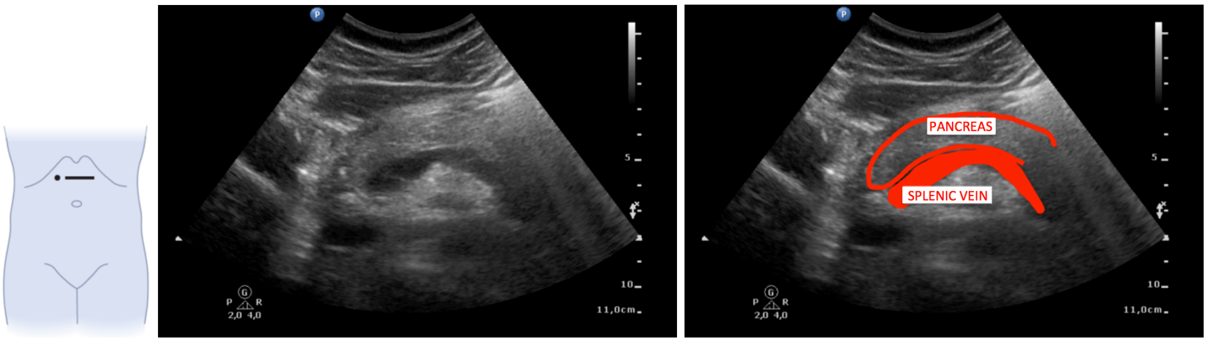

Figure 10. Ultrasonographic examination of the epigastric region.

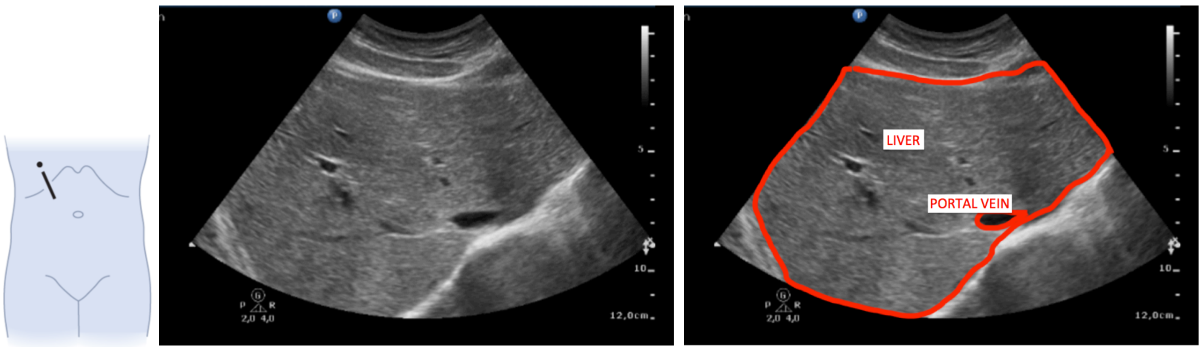

Figure 11. Liver, portal vein.

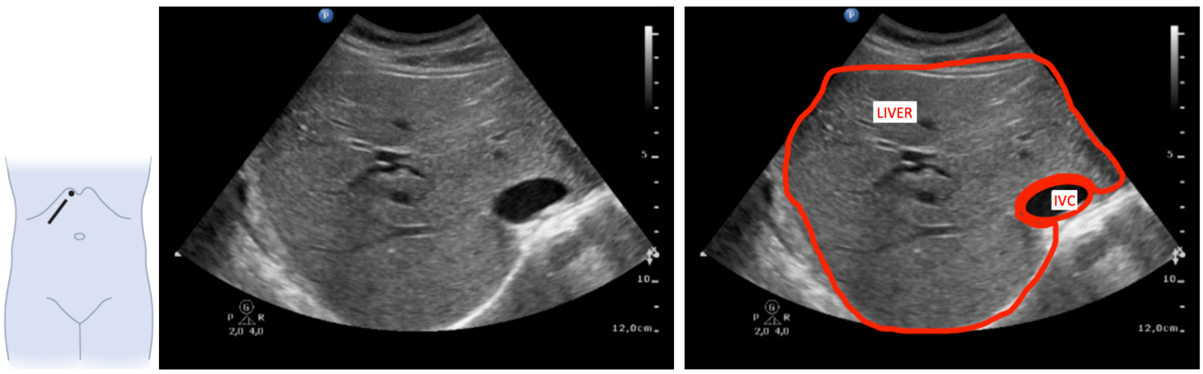

Figure 12. Horizontal scan of the liver and the inferior vena cava (IVC).

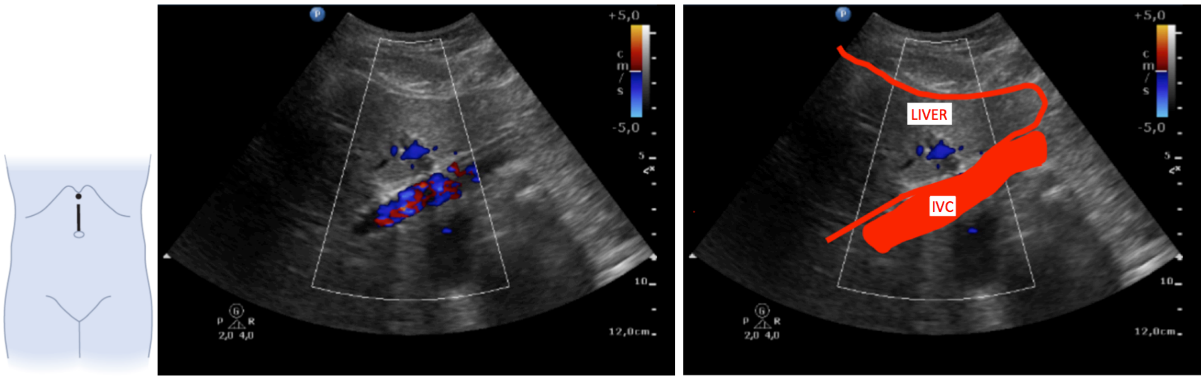

Figure 13. Vertical scan of the liver and the inferior vena cava (IVC) in Doppler mode.

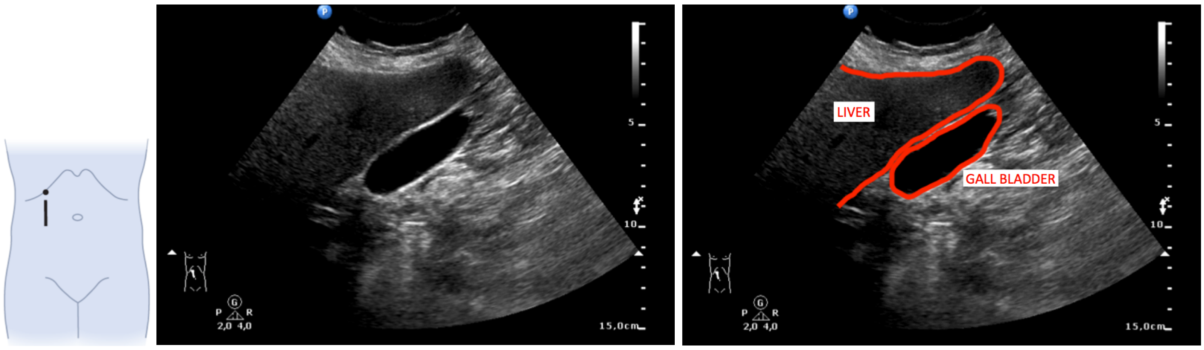

Figure 14. Ultrasonographic image of the gall bladder.

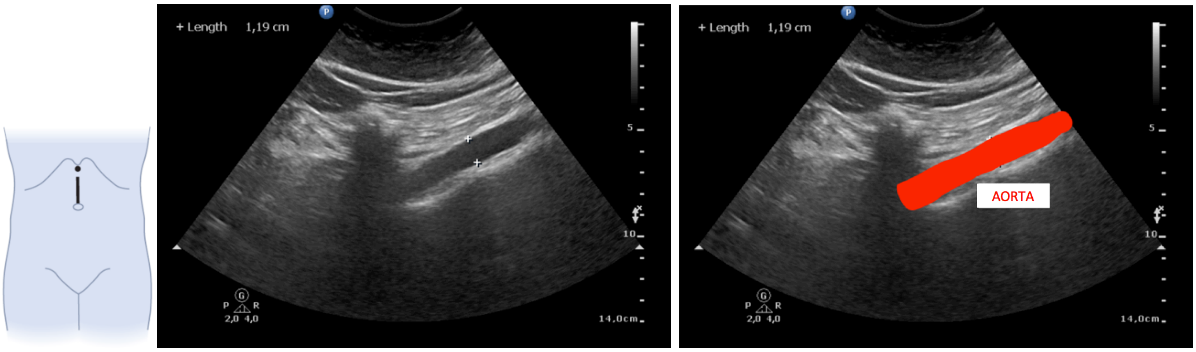

Figure 15. Ultrasonographic image of the abdominal aorta.

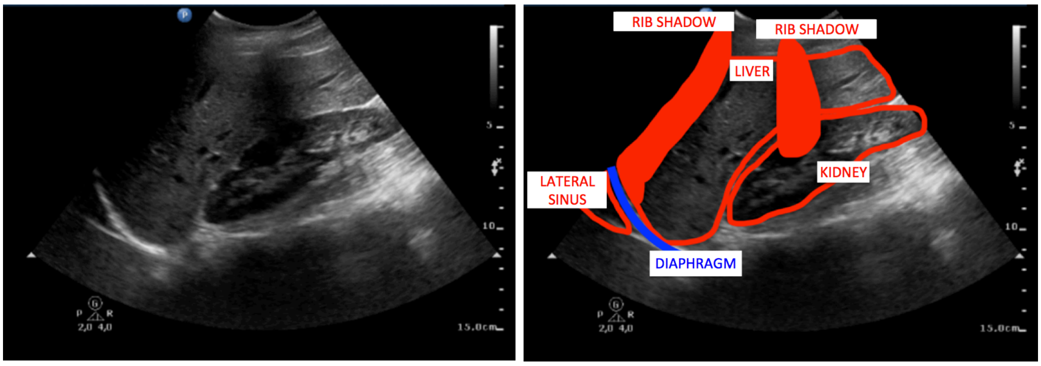

Figure 16. Ultrasonographic image of the right kidney.

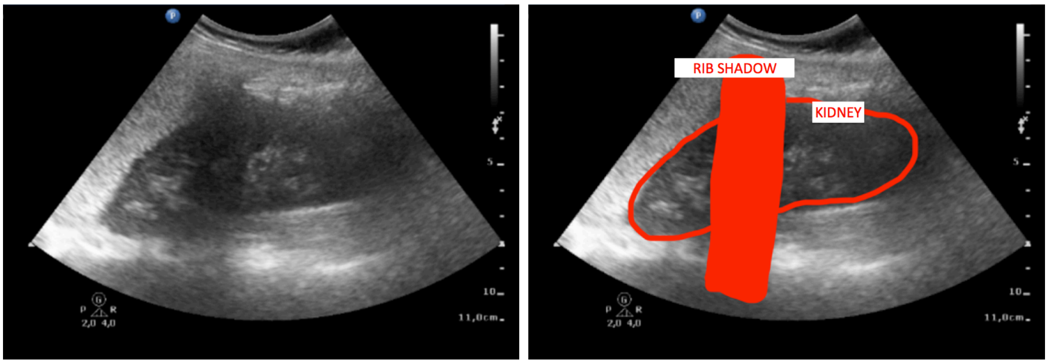

Figure 17. Ultrasonographic image of the left kidney, acoustic shadowing caused by a rib.

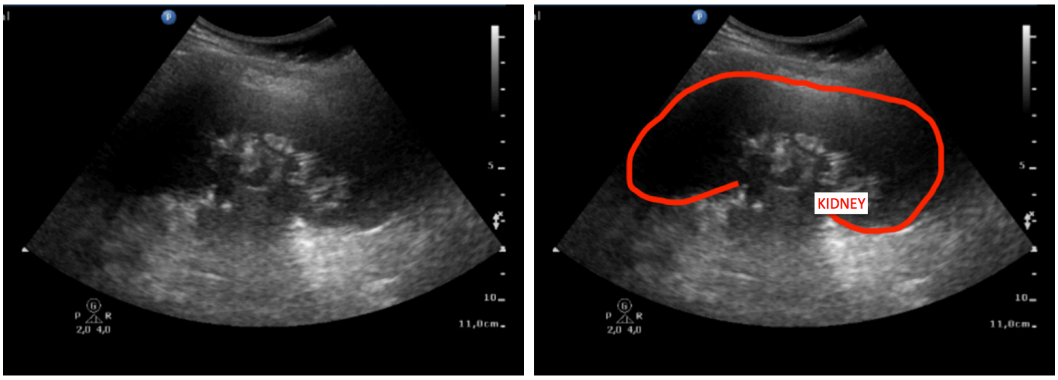

Figure 18. Ultrasonographic image of the left kidney.

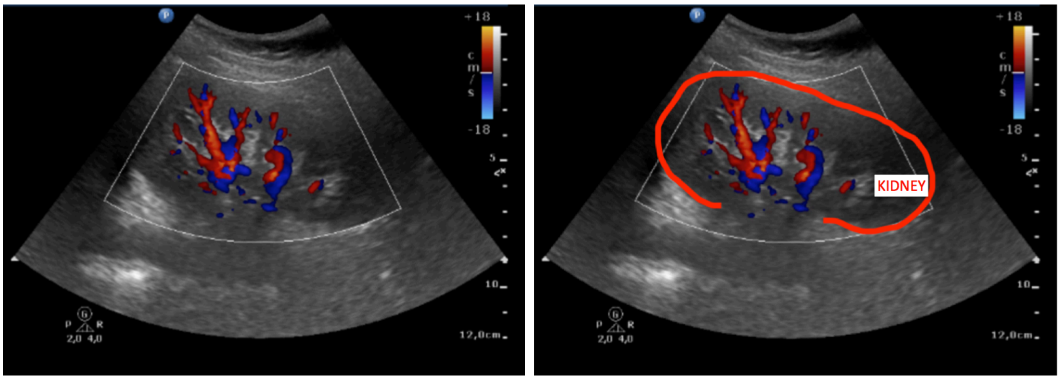

Figure 19. Ultrasonographic image of the left kidney in Doppler mode. It helps to show the position of major blood vessels and the direction of blood flow.

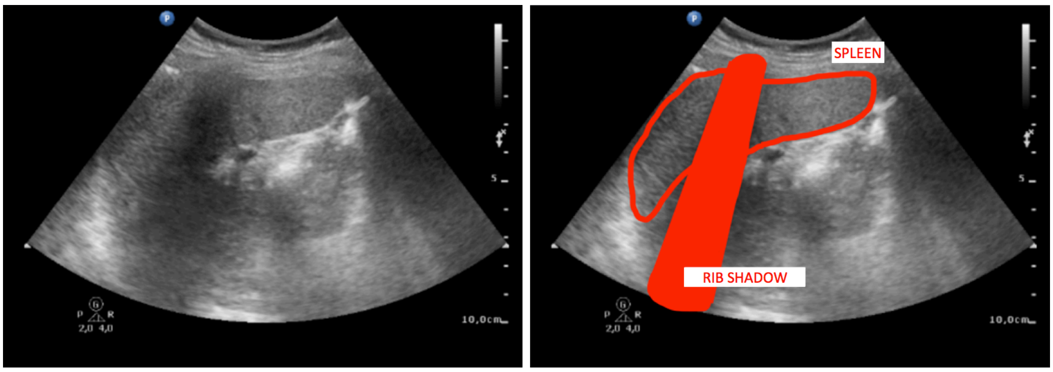

Figure 20. Ultrasonic image of the spleen showing a significant acoustic shadowing caused by a rib.

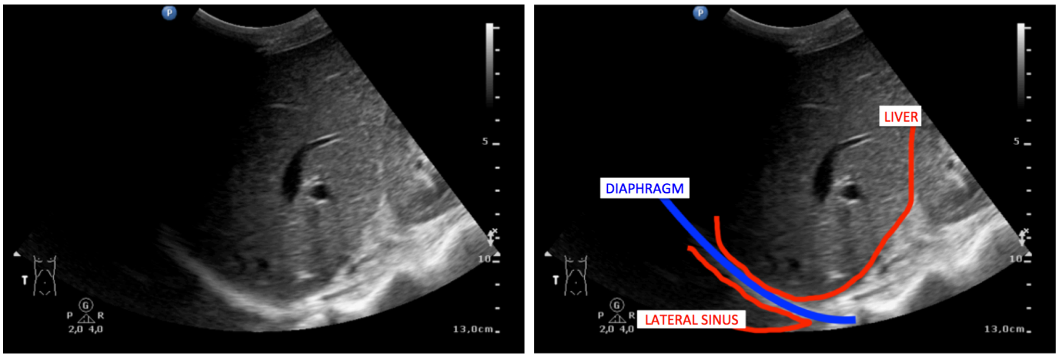

Figure 21. Examination of the right upper quadrant.

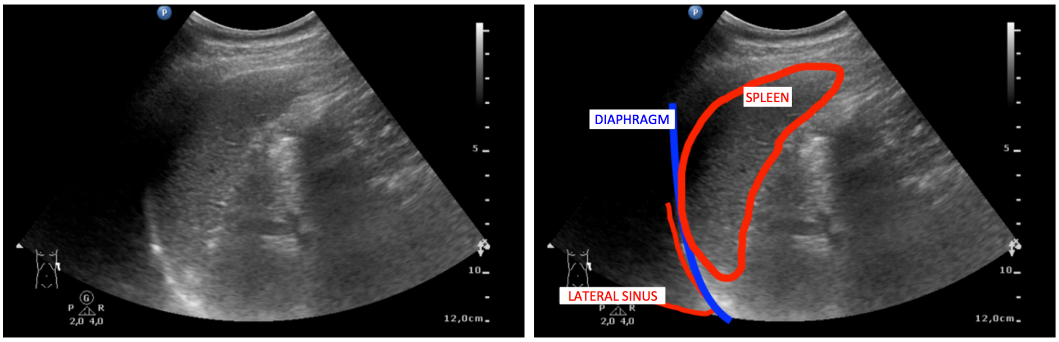

Figure 22. Examination of the left upper quadrant.

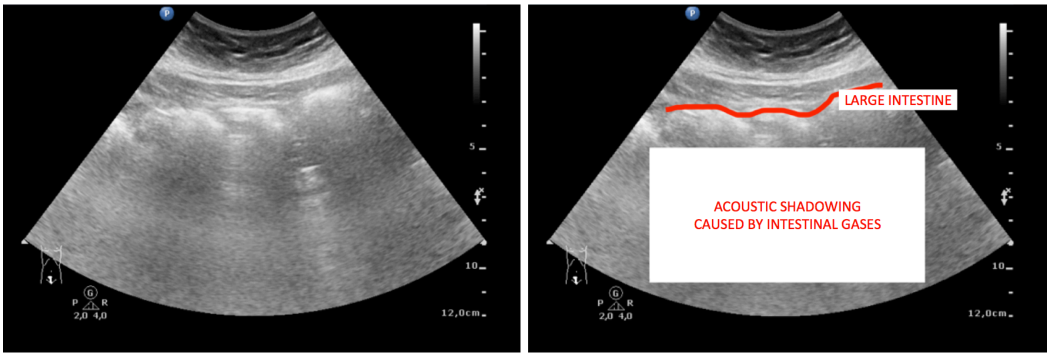

Figure 23. Ultrasonographic image of the large intestine
with significant acoustic shadowing caused by intestinal gases.

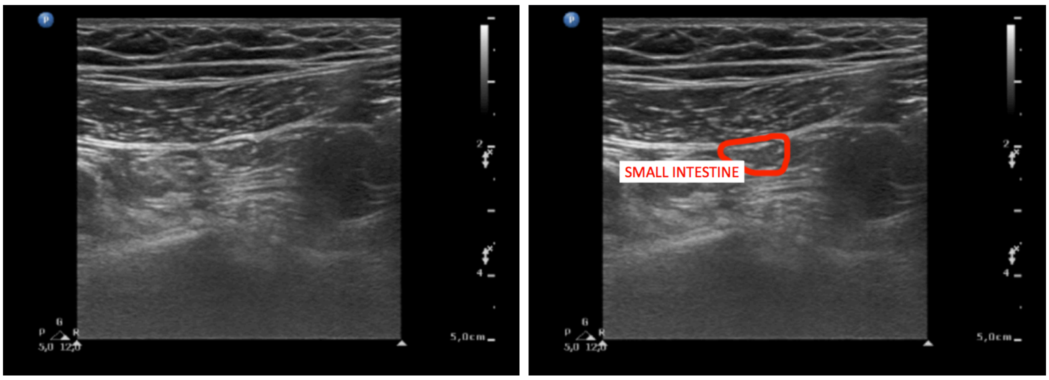

Figure 24. Ultrasonographic image of the small intestine.

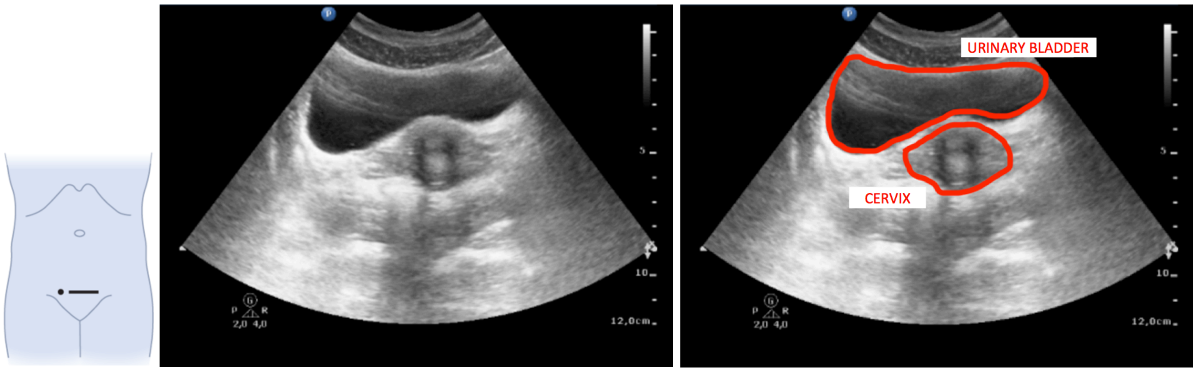

Figure 25. Transverse (horizontal) scan of the urinary bladder and the cervix.

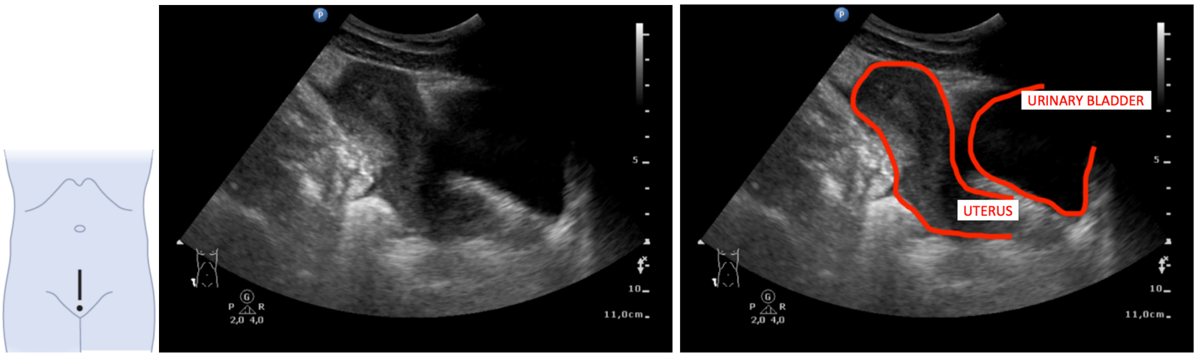

Figure 26. Longitudinal (sagittal) scan of the urinary bladder and the cervix.

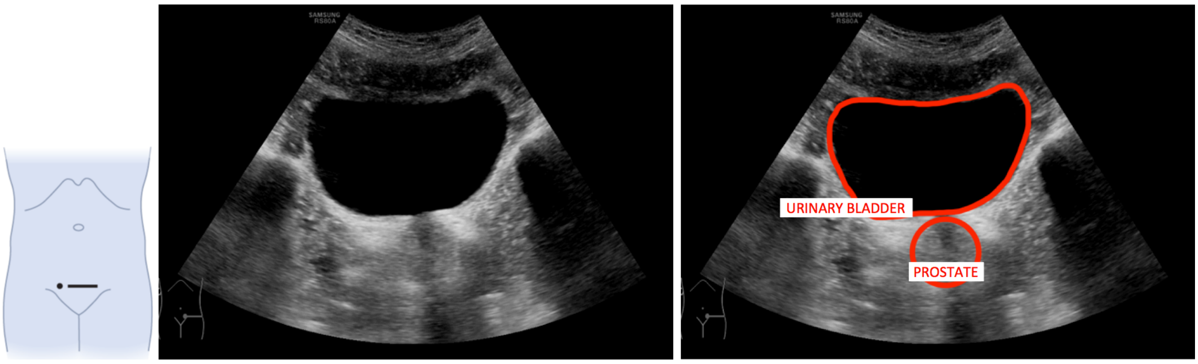

Figure 27. Transverse (horizontal) scan of the urinary bladder and the prostate.

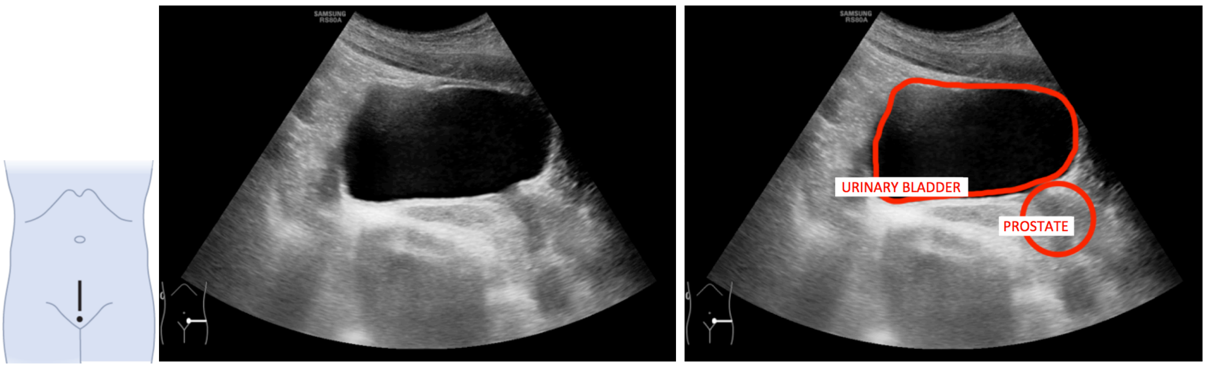

Figure 28. Longitudinal (sagittal) scan of the urinary bladder and the prostate.

10. Examination of the Cervical Region

Use the linear array transducer for the examination of the cervical region because it has the highest resolution in the near field (i.e. near to the transducer). Examine the thyroid gland, the larynx, and the trachea as well as the major blood vessels (carotid artery, jugular vein). It is recommended to observe the significant acoustic shadowing caused by the air content of the larynx and the trachea. It is also recommended to compare the compressibility of the major blood vessels, and to use the Doppler mode.

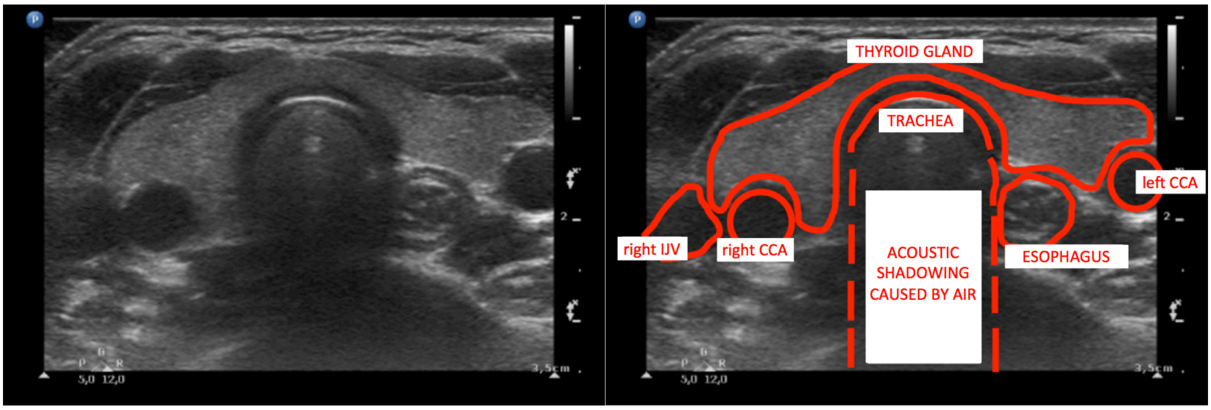

Figure 29. Ultrasonic examination of the cervical region – transverse (horizontal) plane. CCA: common carotid artery; IJV: internal jugular vein

11. Appendix – Emergency Ultrasonography

Ultrasonography plays a key role in modern emergency care. Traumatic patients may suffer from injuries that cannot be discovered during the primary physical examination. The rupture of the heart, a major blood vessel, or a parenchymal abdominal organ may cause an intensive thoracic or abdominal bleeding with highly hidden symptoms – a late observation may cost the life of the patient. The greatest advantage of the bedside, emergency, or – as it is widely known – FAST (***Focused Assesment with Sonography for Trauma***) ultrasound protocol is that it is capable of detecting the accumulation of free liquid – mostly blood – in the thoracic or abdominal cavities, therefore, even clinicians not specializing in medical imaging are expected to learn this method. This targeted examination, of course, should not be mistaken for the detailed abdominal ultrasonographic examination, which – at least in Hungary – is carried out by qualified clinicians specialized in radiology. During the FAST examination a simple algorythm is followed, which is aimed at four regions of the abdominal wall:
1. Substernal region
2. Right upper quadrant
3. Left upper quadrant
4. Suprapubic region (in two planes)

The examination is carried out on a lying patient using a 3.5–5.0 MHz curved transducer, which can visualize a large enough depth. The transducer is held like a pencil with the marker pointing toward the examiner's thumb (transverse scan) or the head of the subject (frontal and sagittal scans). The marker may be a tactile dot, line (as in **Fig. 30**), or a small LED.

Figure 30. Curved transducer and the proper way of holding it.

Substernalis region. In case of substernal view the heart is visualized so it is possible to detect the accumulation of free fluid (incl. blood) in the pericardium as well as significant abnormal cardiac wall motions. Keep in mind that we have to look at the displayed image as if we were the transducer (i.e. looking under the sternum) so it can be understood that the cardiac apex, which is closest to the transducer, will appear at the top of the fan shaped cross-sectional image while the regions further away will appear at the bottom of the image.

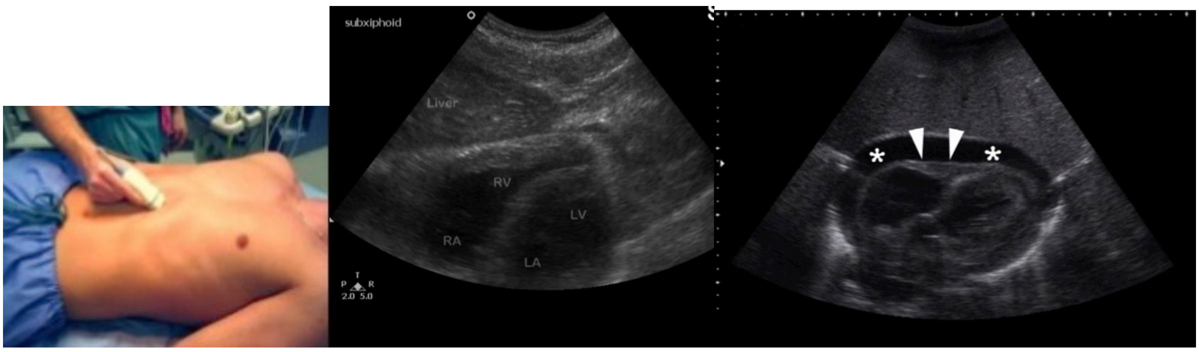

Figure 31. Examination of the substernal region. **a**: Proper positioning of the transducer in order to visualize the cardiac apex. **b**: Visualization of the cardiac apex and the ventricles in the ultrasonographic image. **c**: Ultrasonographic image of free fluid in the pericardium (*).

Right upper quadrant. Any free fluid in the abdomen is accumulated in the deepest point of the abdominal cavity, which in a case of a lying subject is the hepatorenal recess (a.k.a. Morison's pouch). During examination the transducer is placed in the frontal plane aligned with the right middle shoulder line, and the marker is oriented toward the head of the subject. Besides the hepatorenal recess this view enables the visualization of the costodiaphragmatic recess of the pleural cavity, too (Fig. 32).

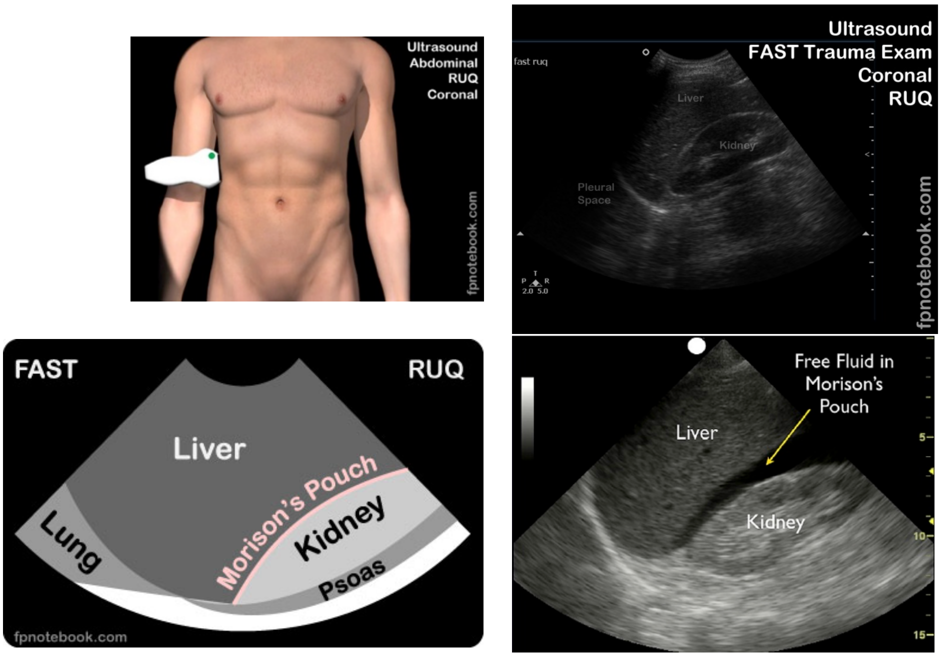

Figure 32. Examination of the right upper quadrant. **a**: Proper positioning of the transducer. **b**: Visualisation of the hepatorenal recess. **c**: Schematic of Morison's pouch. **d**: Free abdominal fluid accumulated in Morison's pouch.

If the subject is in the Trendelenburg position, a higher amount of fluid is accumulated in Morison's pouch making its detection easier. On the other hand, slightly lifting the upper body of the subject makes it easier to detect pleural fluid accumulation (**Fig. 33**).

Figure 33. Ultrasonographic image of pleural free fluid.

Left upper quadrant. On the left side of the abdomen the perisplenic region, the perirenal region, and the left costodiaphragmatic recess. The transducer is positioned on the left side of the body like in the previous case.

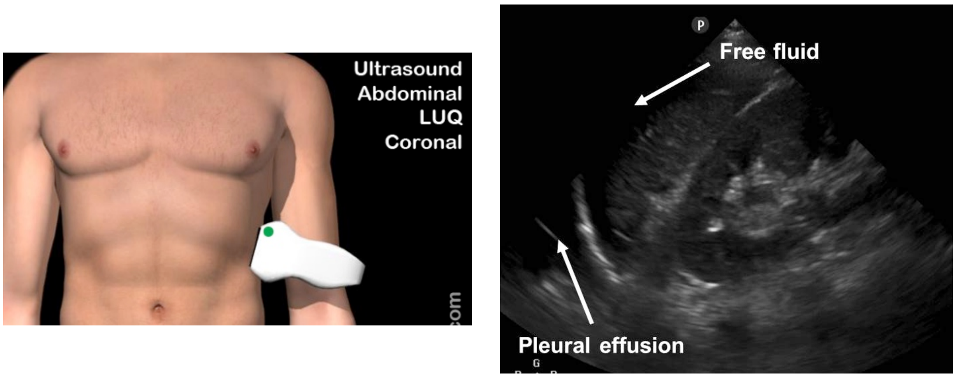

Figure 34. Examination of the left upper quadrant. **a**: Proper positioning of the transducer. **b**: Free fluid in the left costodiaphragmatic recess.

Suprapubic region. The suprapubic view is capable of visualizing free abdominal fluid in the deep pelvic region (Douglas' pouch in women, rectovesical recess in men). Besides the transverse view a sagittal view is also needed, the latter is often called the fifth view.

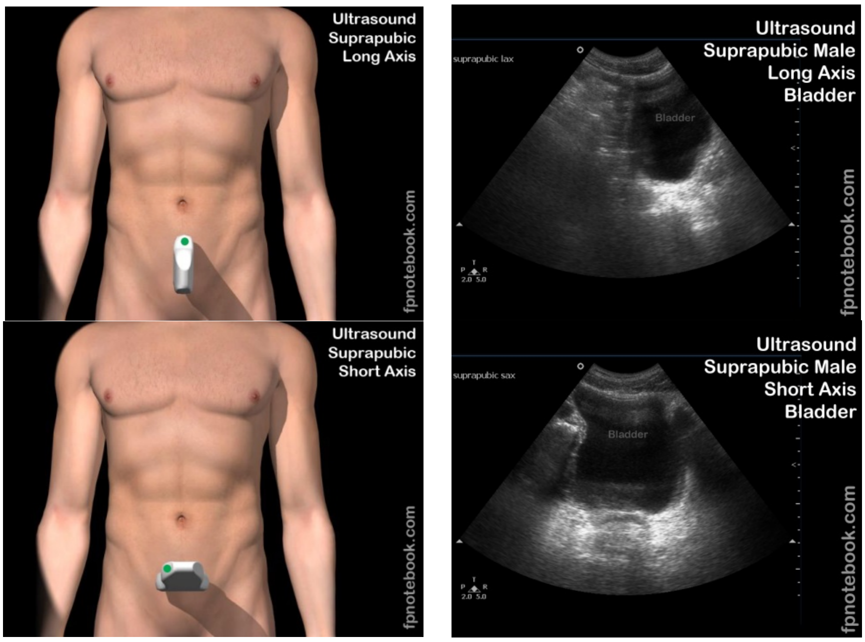

Figure 35. Examination of the suprapubic region. **a**: Longitudinal (sagittal) positioning of the transducer. **b**: Longitudinal (sagittal) scan of the urinary bladder and the prostate. **c**: Transverse (horizontal) positioning of the transducer. **d**: Transverse (horizontal) scan of the urinary bladder and the prostate.

The following "4P" mnemonic helps to recall the order detailed above:
PERICARDIUM, POUCH, PERISPLENIC, PELVIS.

Sources

Fig. 9-25 (incl. legends) were prepared by Dr. Gergely PÖLÖSKEI (Semmelweis University, Department of Radiology).

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